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Catalytic Growth of Single-Wall Carbon Nanotubes: A Study using Environmental Transmission Electron Microscopy

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The final chiral structure of single-wall carbon nanotubes (SWCNTs) can be determined by their initial cap nucleation from a catalyst particle. A mixture of as-synthesized SWCNTs of different structures is now the major challenge for their applications in nanoelectronics. In order to control the assemble processes of the carbon hexagonal network forming homogeneous nanotubes, which strongly relate to catalyst-tube interfacial properties and the diffusion dynamics of carbon atoms around the catalyst nanoparticle, we use environmental transmission electron microscopy (ETEM) to investigate the catalytic growth mechanism of SWCNTs [1] at a low pressure of 0.0001~10 mbar under 450~750 °C. The growth dynamics were monitored in real time, revealing that the choice of catalysts and carbon sources as well as local stress is key to their nucleation and growth termination [2] (Fig. 1). Furthermore, atomic structure and composition of catalysts were characterized *in situ* by means of ETEM with high spatial and temporal resolution. Combined with the analysis on the linking of catalyst features to the structure of SWCNTs, we realized a rearrangement of catalyst particles and multiple growth runs of SWCNTs [3] (Fig. 2).

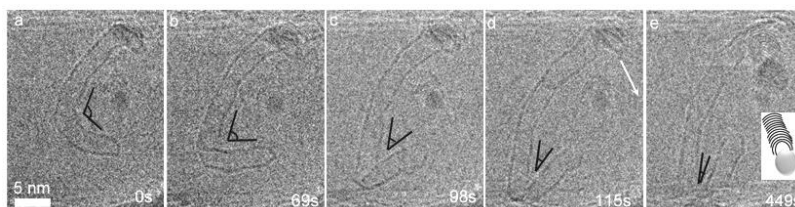


Fig. 1. Growth termination of a SWCNT. One end of the SWCNT was blocked during its growth, which forced the particle attached to the other end to nucleate several caps based on tip growth mode.

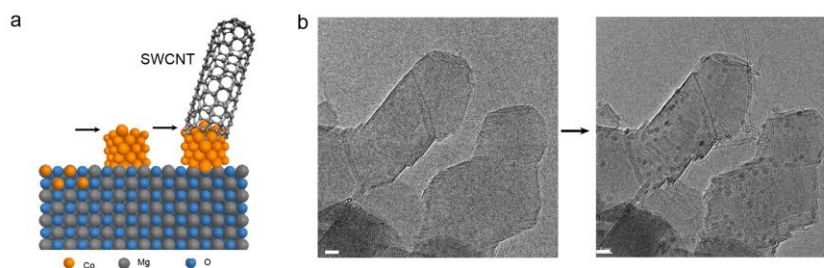


Fig. 2. Schematic (a) and TEM images (b-c) showing the *in situ* formation of catalyst particles and the growth of SWCNTs in the second cycle. Scale bars, 5 nm.

References

- [1] He, M., et al., *Chiral-Selective Growth of Single-Walled Carbon Nanotubes on Lattice-Mismatched Epitaxial Cobalt Nanoparticles*. Sci. Rep., 2013. **3**.
- [2] Zhang, L., et al., *Direct Evidence for Growth Termination and Multiple Nucleation of Single-Wall Carbon Nanotubes*. In preparation.
- [3] Zhang, L., et al., *Renewable Catalysts for Repeated Growth of Single-Wall Carbon Nanotubes*. In preparation.